Software Development: Digitizing Historical Analog Seismograms for Wave Climate Analyses

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LONG-TERM GOALS

The severe winter storm cycle along the California coast during the 1997-98 El Niño-Southern Oscillation (ENSO) focused attention on the variability, and recent apparent intensification, of the wave climate along the West Coast. Few instrumental wave records exist before systematic buoy measurements began in the early 1980's. The number of large storm events reported by Seymour (1996) for 1982-83 ENSO is conspicuously greater than earlier strong ENSO's during the 1940-41 and 1957-58 winters (produced from hindcasts using meteorological data). This suggests that either the effect of strong ENSO's on the wave climate of California has significantly changed, or the wave-climate record prior to 1980 is seriously deficient.

Accurate estimates of the West Coast wave climate can be obtained by inversion of the double-frequency microseism spectrum from broadband seismometer data (Bromirski et al., 1999b). Analyses of NOAA buoy data indicate that the wave climate is very similar along much of the California coast (Bromirski et al., 1999a and 1999b), implying that reconstructed wave measurements from the San Francisco Bay area using seismic data from Berkeley, CA can be extrapolated to the Eel River coastal region, a study area for the ONR sponsored STRATAFORM program. Analog paper seismograms archived at UC Berkeley from 1930-1980 can be used to reconstruct the historical wave record.

Quantitative wave climate reconstructions from 1930 onward are important from two perspectives:

• *Shelf sediment transport and deposition:* The resolution of wave events, their spectral characteristics, and wave climate statistics over time are necessary to understand and model the processes controlling the formation and evolution of event-scale stratigraphy on the continental shelf. Since surface waves induce bottom oscillatory flow that is wave frequency dependent, knowing the spectral character of the wave climate over time is important to understand and model the resuspension, transport, and redisposition of sediments on the sea floor.

• *Global climate change*: Changes in the character and occurrence of extreme storms in the Northeast Pacific during strong ENSO's can be important. In this regard, wave reconstruction from Berkeley data will be absolutely unique in terms of continuity and stability of the measurement

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14. ABSTRACT
The severe winter storm cycle along the California coast during the 1997-98 El Ni??no-Southern Oscillation (ENSO) focused attention on the variability, and recent apparent intensification, of the wave climate along the West Coast. Few instrumental wave records exist before systematic buoy measurements began in the early 1980???s. The number of large storm events reported by Seymour (1996) for 1982-83 ENSO is conspicuously greater than earlier strong ENSO???s during the 1940- 41 and 1957-58 winters (produced from hindcasts using meteorological data). This suggests that either the effect of strong ENSO???s on the wave climate of California has significantly changed, or the wave-climate record prior to 1980 is seriously deficient.

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system, and will thus provide an unbiased record of extreme events in the Northeast Pacific. Reconstruction of the winter wave climate prior to 1980 will establish the variability of the wave climate and the magnitude of any intensification that has occurred since the mid-1970's.

OBJECTIVES

Quantitative estimates of wave energy and climate change from archived seismograms require digital data for spectral processing. However, digitizing scanned analog seismograms using the available version of digitizing software (*NXScan V. 8.1*) from the Berkeley Seismological Laboratory (BSL) was extremely time consuming, making the digitization of large blocks of data infeasible. The goal of this proposal was to modify *NXScan V. 8.1* and substantially improve digitizing efficiency with the aim of digitizing winter months during the 1940-41 and 1957-58 El Niño's. After determining the instrument response function and calibration constants to convert the digitized data from digital units to MKS, inversion of the microseism signals in these data (following the methodology of Bromirski et al. (1999a)) will give estimates of wave climate parameters during these earlier winters to be compared with the buoy-measured wave climate during the 1982-83 and 1997-98 El Niño's. Results from this demonstration study will show the feasibility of the seismic analog-to-digital-to-wave climate methodology. The next step will be to scan and digitize the remaining analog seismograms from 1930 onward so that a complete wave record can be constructed. Funding for this effort will be requested from ONR in the future.

APPROACH

Functional improvements of *NXScan V. 8.1* were needed to enable more efficient digitizing. Development of software modules dealing with timing mark gaps, trace intersections and overlaps, and digitized output time management were necessary. Software development was done by Sara E. Mason, a senior undergraduate computer science major at UC San Diego. *NXScan V. 8.1* was unstable, producing core dumps in various instances. First, code stability was improved. Next, to more effectively assess modifications by improving ease of use, the Graphical User Interface was overhauled.

Scanned seismograms for portions of the 1940-41 and 1957-58 time periods were obtained from the BSL archives. These scanned images are stored as "tif" images, and then converted to raster files for digitizing with *NXScan*.

Each scanned image generally consists of forty-seven thirty-minute traces and two partial traces at the beginning and end of each day. One-minute timing marks cause small gaps at the end of each minute (Fig. 1). Digitizing these day-long images with *NXScan V. 8.1* was hampered by the necessity of manually setting "control points" at both sides of many of the timing mark gaps and almost all trace intersections, as well as when earthquakes and other transients occurred, making the digitizing process extremely time consuming. Trace intersections and overlaps occur regularly when high amplitude storm waves arrive at nearby shorelines. Because digitizing these data is critical for the determination of extreme storm occurrence and characteristics and climate change analyses, software modification to automate trace image tracking as much as possible in these situations was necessary. The necessity of setting control points at gaps and intersections

was substantially eliminated with an algorithm that uses a combination of backward tracking, trace image thickness, and slope estimates from preceding digitized points to constrain the forward digitizing search. Incorrect handling of trace intersections, as well as timing mark discontinuities, is easily identified by visual inspection of the projected digitized trace overlaying the raw image data (see Fig. 1) prior to downloading to an output file.

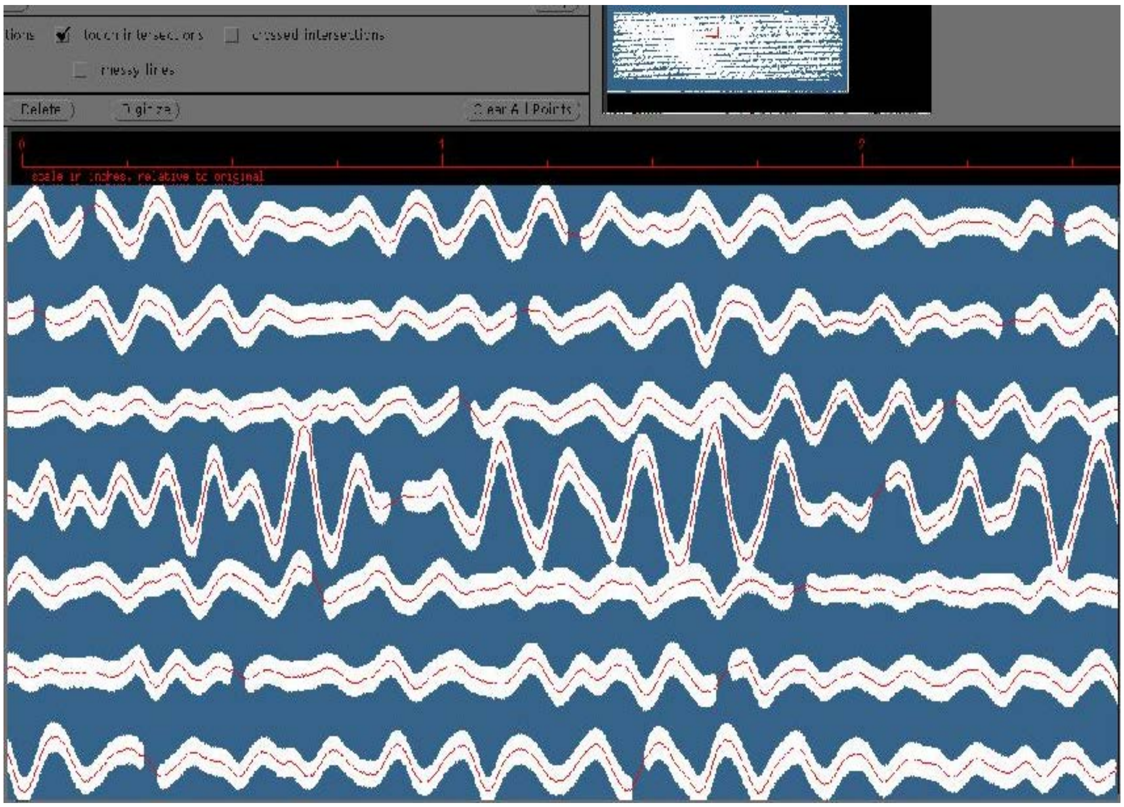

Figure 1: A 2-minute portion of the seismogram for Dec. 6, 1940 viewed with NXScan V. 9.0 shows the trace variation observed in pre-1962 seismograms. The full seismogram image is shown at the top, with the expanded viewing area shown below outlined in red. The scanned traces (thick white lines) show examples of one-minute timing mark gaps and adjacent trace intersections. The projected digitized traces (thin red lines) successfully track past these irregularities.

WORK COMPLETED

Significant progress has been made in improving *NXScan V. 8.1* for digitizing scanned seismogram images. The modified code, *NXScan V. 9.0*, is substantially more efficient than the previous version, with digitizing across timing mark gaps and trace intersections automated in almost all instances. The long-period Wilip-Galitzin seismometer at Berkeley (that produced the seismogram in Fig. 1) was replaced with a long-period Sprengnether seismometer in 1962, with subsequent seismograms having a thinner pen width that makes trace-image tracking more difficult. Further software development is required to efficiently digitize post-1962 seismograms and to automate digitizing across trace overlaps. Digitizing scanned pre-1962 seismogram images with *NXScan V.*

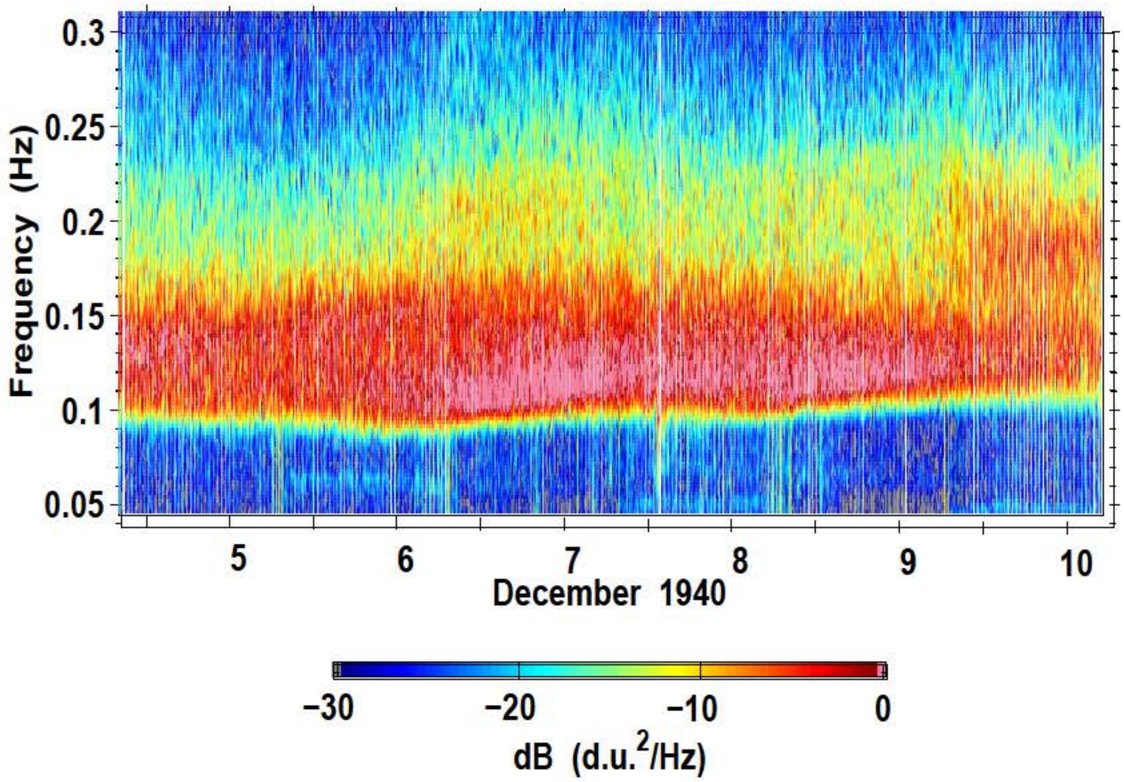

Figure 2: Power spectral variation of digitized seismograms during Dec. 1940, not corrected for either instrument response or calibration constants. Thin vertical white stripes indicate either missing data or time periods where the scanned image quality was not adequate for digitizing, generally at trace edges.

8.1 required about 15 min (or more, depending on image quality) per 30 min trace. *NXScan V. 9.0* requires less than 30 min per day-long seismogram (48 traces in pre-1962 seismograms), a very significant improvement.

RESULTS

A scanned seismogram image for Dec. 25, 1940 viewed with *NXScan V. 9.0* is shown in (Fig. 1). No control points were needed to successfully navigate the timing mark gaps and trace intersections shown. The temporal variation of raw spectral levels for digitized data from Dec. 1940 (Fig. 2) shows two energy concentrations (beginning on Dec. 6 and Dec. 8, respectfully) that are characteristic of double-frequency microseisms (high amplitude energy in the [0.09,0.25] Hz band at twice the wave frequency). These signals result from wave-wave interactions at the arrival of dispersed gravity waves (swell) from two storms at nearby coastal locations, with the spectral variation observed in Fig. 2 similar to modern digitally-recorded seismic data (Bromirski and Duennebier, (in press); Bromirski et al. (1999a)). Associated primary microseisms at the frequency of the waves are not clearly identifiable in the [0.05,0.09] Hz band, probably because these spectra do not include an instrument response correction (not yet available). The Galitzin seismometer

that recorded these signals has a natural period of 12 sec, causing the peak in the raw spectra near 0.1 Hz to be elevated relative to 0.06 Hz and 0.25 Hz levels. However, the character of the spectral variation observed and the percentage of the data digitized indicate that the *NXScan* code modifications have been successful, and that these data can be inverted to obtain gravity-wave parameter estimates at a more than adequate sampling density to enable quantitative characterization of the wave climate prior to 1980 when instrumental buoy measurements are unavailable.

IMPACT / APPLICATIONS

Reconstruction of the coastal wave record is important to the State of California. Analyses of the wave climate over the past decades (using meteorologically-based reconstructions and buoy data) show major upward trends in large, long-period wave episodes, especially since the mid-1970's (Seymour, 1996). Because these trends obviously have important impact on design criteria for coastal construction, beach nourishment and evaluations of coastal erosion, wave climate data from earlier decades will be of significant economic value from both "design-wave" and insurance liability perspectives to establish whether the observed variation in recent decades is in fact a long-term trend or cyclicity at time scales longer than the currently available wave record.

RELATED PROJECTS

Tide gauge data from 1858 onward from San Francisco Bay is currently being studied with funding from the California Department of Boating and Waterways. The variance of non-tide residuals shows "storminess" cycles on time scales of 10-20 yr (Bromirski and Flick, 2001), consistent with other climatological studies (e.g. Trenberth and Hurrell, 1994; Graham, 1994; Schneider et al., submitted). Extending the wave record backward to 1930 from inversion of microseism data would help characterize the wave climate variation observed during the last 25 years. Wave climate data showing decadal-scale cycles in long-period wave energy would validate results from tide gauge data and other climatological studies, and provide valuable information for coastal planning.

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